

Retrieval Modeling and Error Sources for Microwave Remote Sensing of Ocean Surface Salinity

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Abstract —A set of geophysical error sources for the microwave remote sensing of ocean surface salinity have been examined. The error sources include the sea surface temperature, sea surface roughness, atmospheric gases, ionospheric Faraday rotation, and planetary and galactic emission sources. It is shown that the brightness temperature errors of a few Kelvin can be expected for most of these error sources. The key requirements for corrections are the knowledge accuracy of 0.5°C for the sea surface temperature (SST), 10°C for the surface air temperature, 0.2° accuracy for the Faraday rotation, and 0.3 m/s for the surface wind speed. We suggest the use of data products from AMSR-type instruments for the corrections of SST and liquid cloud water, the numerical weather analysis for the surface air temperature, and on-board radar and polarimetric radiometer channel for surface roughness and Faraday rotation. The most significant sky radiation is from the sun. A careful design of the antenna is necessary to minimize the leakage of solar radiation or reflection into the antenna side lobe. The narrow-band radiation from galactic hydrogen clouds is also significant, but can be corrected with an accurate radio sky survey or minimized with a notched (band-rejection) filter centered at 1.420 GHz in the receiver. The other planetary and galactic radio sources can be flagged with negligible data loss. We have performed a sampling analysis for a polar-orbiting satellite with 900 km swath width to determine the number of satellite observations from a given surface pixel over an extended duration. Under the assumption that the observations from different satellite passes are independent, it is suggested that an accuracy of 0.1 psu is reachable for global monthly 1-degree latitude and 1-degree longitude gridded products.

INTRODUCTION

Global measurements of sea surface salinity (SSS) are important for studying the ocean circulations and rainfall and consequently for improving the estimates of seasonal to interannual climate predictions. The global ocean surface salinity is viewed as a missing element in the ocean modeling and flux studies.

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The challenge for the SSS remote sensing is that the L-band sea surface T_b is influenced by many other geophysical parameters, such as sea surface roughness, sea surface temperature, ionospheric Faraday rotation, solar radiation, and atmospheric gases. The effects of most parameters are non-negligible compared with the sensitivity of T_b to SSS. In this paper, we focus on the effects of sea surface roughness.

MEASUREMENT SENSITIVITY

In the past, the sensitivity of microwave radiation to water salinity was studied primarily using the dielectric constant model proposed by [1]. The latest effort to improve the dielectric constant model of sea water was undertaken by [2] with new laboratory measurements covering a large range of frequencies, temperature, and salinity. The Ellison model has been used to examine the brightness temperatures of a smooth water surface at 1.4 GHz . Fig. 1 illustrates the dependence of brightness temperatures of a flat surface on the surface salinity at 40° incidence angle and six water temperatures. The brightness temperatures are more sensitive to SSS for warmer and more saline waters. The two lower panels plot the derivatives of T_v and T_h as a function of SSS. For the surface salinity of open oceans (typically greater than 30 psu), the sensitivity is in the range of 0.35 to 0.8 Kelvin/psu for vertical polarization and 0.2 to 0.6 Kelvin/psu for horizontal polarization. The vertical polarization is about 30% more sensitive to the SSS than the horizontal polarization.

SURFACE ROUGHNESS EFFECTS

Experimental evidence on the effects of surface roughness on L- and S-band microwave brightness temperatures of sea surfaces can be found in [3,4]. These observations suggest that the L-band sea surface brightness temperatures increase by a few tenths of Kelvin for a wind speed increase of 1 m/s .

To examine the influence of surface roughness effects on ocean surface salinity retrieval, JPL has developed a dual-frequency (L-/S-band), dual-polarized microwave radiometer and radar. This system was deployed on the National Center for Atmospheric Research (NCAR) C-130 aircraft for three flights on July 17-19, 1999, across the Gulf Stream off

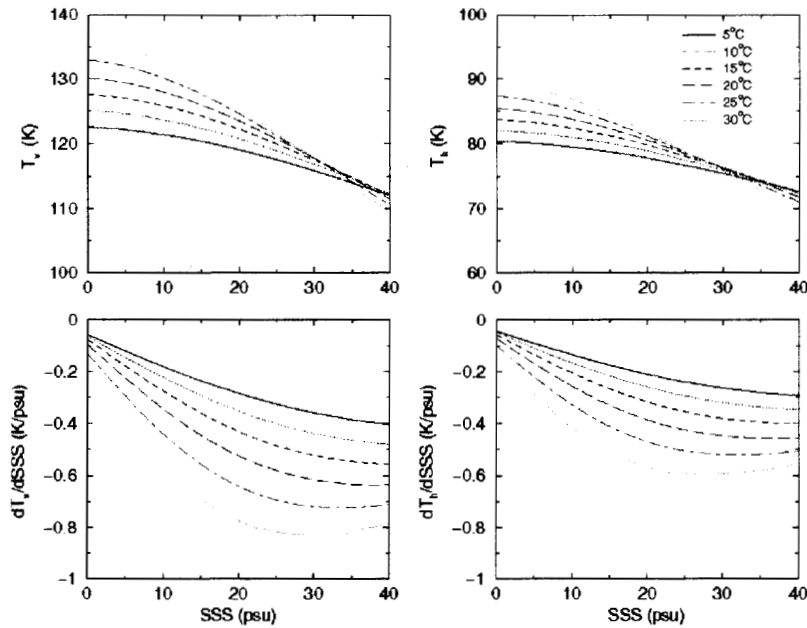


Fig.1 The sensitivity of sea surface brightness temperatures to water salinity at 40° incidence, predicted by the Ellison model [1]. The two upper panels plot T_v and T_h versus the salinity at six water temperatures. The two lower panels plot the derivatives to indicate the sensitivity to SSS.

Norfolk, Virginia. The in-situ measurements were performed by the Duke Cape Hatteras research vessel.

The ship data indicated that the wind speed near and across the Gulf Stream was low and highly variable in the range of 0-6 m/s on July 17. It appeared that the aircraft flight track had intercepted several areas with smooth surfaces across and near the Gulf Stream front. Fig. 2 illustrates the coincidental radiometer and radar measurements made at 40° incidence from one flight line. The area with a smooth surface is indicated by a low radar backscatter (about -30 dB for vertical polarization and -45 dB for horizontal polarization.) The radiometer data also dip over the same area. T_v and T_h change by about 1.4 and 2.4 Kelvin, respectively, across the region with a sharp surface roughness (perhaps wind) gradient. Under the assumption of a linear relationship and a change of wind speed by 6 m/s, the slope of brightness temperature versus wind speed is 0.23 K per m/s for vertical polarization and 0.40 K per m/s for horizontal polarization. For this case study, the JPL data provide support to Swift's horizontally polarized data, while JPL's results are more sensitive to the roughness than Hollinger's for both polarizations. If we assume that the data from all three sources are correct, the conflicts among them suggest that there are other mechanisms, influencing the roughness of sea surface, in addition to the winds.

The JPL data set suggests that the direct information of surface roughness can be provided by microwave radar

backscatter. We have examined the brightness temperature versus the normalized radar cross sections for vertically polarized transmit and receive (σ_{vv}) and horizontally polarized transmit and receive (σ_{hh}). A quasi-linear relationship appears between the excess brightness temperatures and radar signals, $\Delta T_b = A\sigma_0$. This model suggests the feasibility of using radar data to remove the excess brightness temperatures. The upper panel in Fig. 2 plots the corrected brightness temperatures using σ_{hh} with $A=240$ for T_v and 400 for T_h . The sharp change of brightness temperatures is reduced. The two lower panels illustrate the SSS retrieved from the brightness temperature data plotted in the upper panel. The SSS estimates from T_v data have a change of about 1 psu across the front and the estimates from T_h change by about 3 psu. These changes correlate with the variations of surface roughness. The estimates from the corrected brightness temperature data do not have such a salinity gradient. (The ship data acquired from multiple transects at different latitudes across the Gulf Stream front to the west of the flight line are plotted as a reference.) Because the salinity was not expected to have a significant change to the east of the Gulf Stream front, the results support the use of radar data for surface roughness correction.

The previous data sets and JPL aircraft measurements indicate the possibility of utilizing the polarization diversity to reduce the effects of surface roughness. This algorithm explores the differing polarization behaviour of brightness

temperatures, which indicates that a linear combination of T_v and T_h at above 40° incidence can eliminate the effects of surface roughness. For example, the quantity, $T_{b1}=T_v-aT_h$, could be less dependent on wind speed, with $a=0.6$ appearing to be a good choice at 40° incidence. The coefficient "a" is expected to be closer to one for smaller incidence angles and decreases with increasing incidence angles. The major drawback is that T_{b1} is about 50% less sensitive to SSS than T_v . The derivative of T_{b1} with respect to SSS reduces to about 0.45 K/psu at 30°C water temperature and about 0.2 K/psu at 5°C water temperature.

SUMMARY

A detailed analysis of various geophysical error sources that influence the microwave remote sensing of ocean surface salinity has been performed. Many of them are shown to have an influence of a few Kelvin, non-negligible compared with the sensitivity of L-band sea surface brightness temperatures to salinity. An accurate knowledge of these parameters is necessary to enable a correction of the microwave measurements for SSS retrieval. A set of assumptions, which can be translated to the requirements on retrieval algorithms and instrument characteristics, have been explored to estimate the accuracy of global gridded salinity products. It is shown that an accuracy of 0.1 psu is reachable for a monthly averaged retrieval for a polar-orbiting satellite with a swath width of more than 900 km. A key factor to enable the accuracy of satellite measurements is the stability of the instrument or calibration device. The instrument has to be calibrated to an accuracy of better than 0.2 K in terms of temporal variability. This level of precision is believed to be achievable, but it is a non-trivial task. Extreme care has to be taken for the design and development of sensors.

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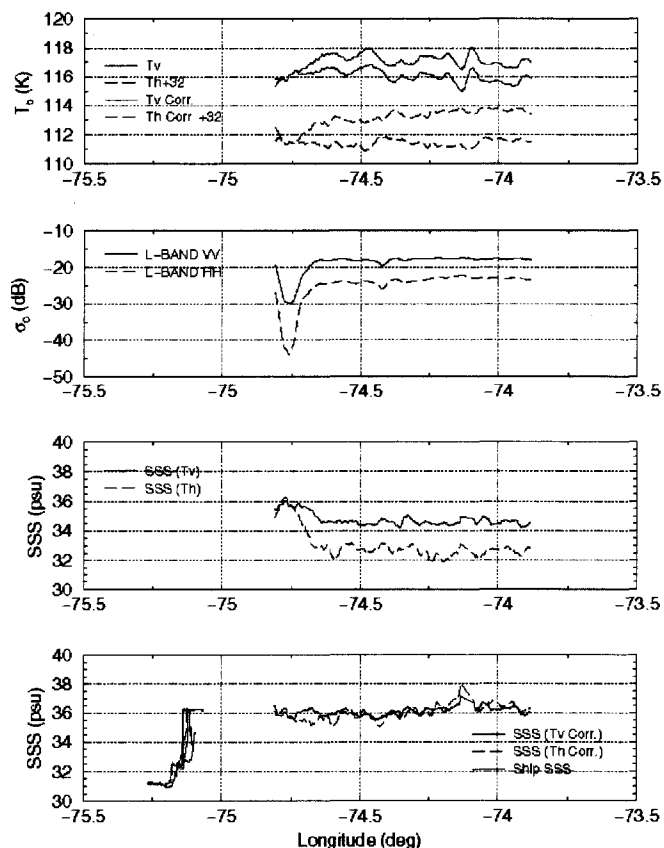


Fig.2 L-band microwave radiometer and radar observations of sea surfaces at 40° incidence acquired on July 17, 1999, near the Gulf Stream off Norfolk, Virginia. The upper panel plots the vertically and horizontally polarized brightness temperatures. T_v and T_h are the sensor data. The curves labeled by "Corr." are the data subtracted by $A \sigma_{hh}$ with $A=400$ for T_h and 200 for T_v . The second panel from the top plots the normalized radar cross section (NRCS) for vertically polarized transmit and receive (VV) and horizontally polarized transmit and receive (HH). The two lower panels plot the SSS retrieved from the data illustrated in the upper panel.